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Dated 10 October 2000

PATENTS ACT 1977

PATENTS FORM NO. 1/77 ([illegible]ed 1982)

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E
29 SEP 1999
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Form 1/77 P1578

29SEP99 E480035-1 C02151
P01/7700 0.00 - 9922919.7

29 SEP 1999

REQUEST FOR GRANT OF A PATENT

9922919.7

THE GRANT OF A PATENT IS REQUESTED BY THE UNDERSIGNED ON THE BASIS OF THE PRESENT APPLICATION

I Applicant's or Agent's reference *(Please insert if available)* P1578

II Title of invention Transducer systems

III Applicant or Applicants *(See note 2)*

Name (First or only applicant)........1... IPR Limited

Country...England.......State.................ADP Code No.................

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7375561002

Name (of second applicant, if more than one)..........................

......................Country......................State......................

Address ....

IV Inventor (see note 3)

Anthony Hooley

(a) The applicant(s) is/are the sole/joint inventor(s)
or
(b) A statement on Patents Form No 7/77 is/will be furnished

V Name of Agent (if any) *(See note 4)* J P L Hooper ADP CODE NO ~~0627302001~~

VI. Address for Service *(See note 5)*

5 Haslingfield Road, Harlton, Cambridge CB3 7ER 4623024601

VII Declaration of Priority *(See note 6)*

Country	Filing date	File number

VIII The Application claims an earlier date under Section 8(3), 12(6), 15(4), or 37(4) *(See note 7)*

Earlier application or patent number.................and filing date.................

T5AF 0361

IX Check List *(To be filled in by applicant or agent)*

A The application contains the following number of sheet(s)

1 Request . . . . . 1 . . . . Sheet(s)

2 Description . . . . 11 . . . . Sheet(s)

3 Claim(s) . . . . . . No . . . . Sheet(s)

4 Drawing(s) . . . . 2 . . . . Sheet(s)

5 Abstract . . . . . . No . . . . Sheet(s)

B The application as filed is accompanied by:-

1 Priority document . N/A

Translation of priority document N/A

3 Request for Search . . . . . . No. .

4 Statement of Inventorship and Right to Grant . . . . No. .

X It is suggested that Figure No. . . . . . . 1 . . . . of the drawings (if any) should accompany the abstract when published.

XI Signature *(See note 8)*

(J P L Hooper) Agent for the Applicants

NOTES:

1. This form, when completed, should be brought or sent to the Patent Office together with the prescribed fee and two copies of the description of the invention, and of any drawings.

2. Enter the name and address of each applicant. Names of individuals should be indicated in full and the surname or family name should be underlined. The names of all partners in a firm must be given in full. Bodies corporate should be designated by their corporate name and the country of incorporation and, where appropriate, the state of incorporation within that country should be entered where provided. Full corporate details, eg a "corporation organised and existing under the laws of the State of Delaware, United States of America", trading styles, eg "trading as xyz company", nationality, and former names, eg "formerly (known as) ABC Ltd" are *not* required and should *not* be given. Also enter applicant(s) ADP Code No. (if known).

3. Where the applicant or applicants is/are the sole inventor or the joint inventors, the declaration (a) to that effect at IV should be completed, and the alternative statement (b) deleted. If, however, this is not the case the declaration (a) should be struck out and a statement will then be required to be filed upon Patent Form No 7/77.

4. If the applicant has appointed an agent to act on his behalf, the agent's name and the address of his place of business should be indicated in the spaces available at V and VI. Also insert agent's ADP Code No. (if known) in the box provided.

5. An address for service in the United Kingdom to which all documents may be sent must be stated at VI. It is recommended that a telephone number be provided if an agent is not appointed.

6. The declaration of priority at VII should state the date of the previous filing and the country in which it was made and indicate the file number, if available.

7. When an application is made by virtue of section 8(3), 12(6), 15(4) the appropriate section should be identified at VIII and the number of the earlier application or any patent granted thereon identified.

8. Attention is directed to rules 90 and 106 of the Patent Rules 1982.

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File No: P1578

App. No:
App. Date:

PATENTS ACT 1977

PATENT SPECIFICATION

APPLICANTS:- 1... IPR Limited
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TITLE:- Transducer systems

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PRIORITY:- None

AGENT:- **John Hooper, Cambridge, England**

Transducer systems

This invention is concerned with transducer systems, and relates in particular to such systems that can be utilised to provide electronically-steerable loudspeakers and/or microphones - and combinations thereof - whose sound radiation and/or sensitivity patterns can be controlled and steered to point, or not to point, in any chosen direction.

One of the problems to be dealt with whenever a loudspeaker system is driven by amplified signals originating from microphones physically disposed near the loudspeakers, such as is often the case with a Public Address (PA) system, is that of "howl", also known as "howl-round" or positive electro-acoustic feedback. In this condition a loudspeaker's output reaches (often in a fairly narrow frequency band), and is picked up by, a microphone, and is then amplified and fed to the loudspeaker, and from which it again reaches the microphone ... and where the received signal's phase and frequency matches the present microphone signal's output the combined signal rapidly builds up until the system saturates, and emits a loud and unpleasant whistling, or "howling" noise.

Anti-feedback or anti-howl-round devices are known for reducing or suppressing acoustic feedback. They can operate in a number of different ways. For example, they can reduce the gain - the amount of amplification - at specific frequencies where howl-round occurs, so that the loop gain at those frequencies is less than unity. Alternatively, they can modify the phase at such frequencies, so that the loudspeaker output tends to

cancel rather than add to the microphone signal. Another possibility is the inclusion in the signal path from microphone to loudspeaker of a frequency-shifting device (often producing a frequency shift of just a few hertz), so that the feedback signal no longer matches the microphone signal.

None of these methods is entirely satisfactory, and the invention proposes a new way, appropriate in any situation where the microphone/loudspeaker system employs a plurality of individual transducer units - these may be either the loudspeakers or the microphones - arranged as an array - and in particular where the loudspeaker system utilises a multitude of such transducer units as disclosed in, say, the Specification of International Patent Publication WO 96/31,086. More specifically, the invention suggests that the phase and/or the amplitude of the signal fed to or received by each transducer unit - fed to each loudspeaker or received by each microphone - be arranged such that the effect on the array is to produce a significantly-reduced "sensitivity" level in one or more chosen direction (along which may actually or effectively lie a complementary unit - a microphone to a speaker or other sound source, or a speaker or other sound source to a microphone). In other words, the invention proposes that the loudspeaker unit array produces output nulls which are directed wherever there is a microphone that could pick up the sound and cause howl, or where for some other reason it is undesirable to direct a high sound level, and/or that the microphone array produces input nulls which are directed wherever there is a loudspeaker (or other sound source) from which it is undesirable to receive much sound energy.

In one aspect, therefore, this invention provides an electro-acoustic transducer system in which there is an array of a plurality of spatially-distributed sonic acoustic transducers either radiating sound (loudspeakers) or receiving sound (microphones), and wherein:

each transducer is connected to a phase control device (and optionally an amplitude control device; each of these control devices may be either individual to each transducer, or shared amongst a number of the transducers);

the phase control devices are implemented as variable signal-path-time-delay elements, thus allowing the system to operate over a broad frequency band; and

the time delays and amplitude settings applied to each transducer are chosen so that the array produces one or more "anti-beam" in the direction of which the array sensitivity - the sound radiation output from the array, in the transmitting transducer case, or the reception sensitivity to sound radiation of the array, in the receiving transducer case - is significantly reduced, so creating partial or almost-total "nulls" in the response pattern of the array.

By appropriate connection of multiple phase-shifting/amplitude-control elements (PSACEs) *per* array element, and then by the appropriate selection of time delay and optionally gain settings of each group of these PSACEs, multiple such partial or near-total nulls may be produced.

The advantages of the array or the invention are manifold. One such advantage applies where the transducer array is a loudspeaker (i.e. a transmitter of

sonic acoustic energy), when sound energy may be selectively NOT directed, and so "quiet spots" may be produced, whilst leaving the energy directed into the rest of the surrounding region largely unchanged (though it may additionally be shaped to form a positive beam or beams). This is particularly useful in the case where the signals fed to the loudspeaker are derived totally or in part from microphones in the vicinity of the speaker array: if an "anti-beam" is directed from the speaker array towards such a microphone, then the loop-gain of the system, in this direction *alone*, is reduced, and the likelihood of howl-round may be reduced; i.e. a null or partial null is located at or near to the microphone. Where there are multiple microphones, as is common on stages, or at conferences, multiple anti-beams may be so formed and directed at each of the microphones.

Another advantage is seen where the array transducer is a microphone (i.e. a sound receiving device), when such anti-beams may be directed towards unwanted sound sources to reduce pick-up from those sources, whilst leaving sensitivity in other regions around the array largely unchanged, or as selected by the positive beaming abilities of the array.

A third benefit is also seen where the array transducer is a loudspeaker (as in the first case mentioned above), when, where one or more region of the listening area is adversely affected by reflections off walls or other boundaries, anti-beams may be directed at those boundaries to reduce the adverse effects of any reflections therefrom, thus improving the quality of sound in the listening area.

Yet another benefit is seen where the array transducer is a microphone (as in the second case

mentioned above), again where unwanted signals are being received from reflections off boundaries, when again anti-beams may be directed at those boundaries to reduce or nullify such adverse effects.

A problem may arise with the speaker system of the invention where the wavelength of the sound being employed is at an extreme compared with the physical dimensions of the array. Thus, where the array-extent in one or both of the principle 2D dimensions of the transducer array is such that it is smaller than one or a few wavelengths of sound below a given frequency (F_c) within the useful range of use of the system, then its ability to produce significant directionality in either or both of those dimensions will be somewhat or even greatly reduced. Moreover, where the wavelength is very large compared to one or both of the associated dimensions, the directionality will be essentially zero. Thus, the array is in any case ineffective for directional purposes below frequency F_c. Worse, however, is that an unwanted side-effect of the transducer array being used to produce anti-beams is that, at frequencies much below F_c, the output energy in all directions can be unintentionally much reduced, because the transducer array, considered as a radiator, now has multiple positively- and negatively-phased elements spatially separated by much less than a wavelength, producing destructive interference the effect of which is largely to cancel the radiation in many if not all directions in the far field - which is not what is desired in the production of anti-beams.

To deal with this special case, then, the driving signal to the transducer array should first be split into frequencies-below-frequency-F_B (BandLow) and

frequencies-above-F_s (BandHigh), where F_s is somewhere in the region of F_c (i.e. where the array starts to interfere destructively in the far field due to its small size compared to the wavelength of signals of frequency below F_s). Then, the BandHigh signals are fed to the transducer array elements in the standard array manner *via* the PSACEs, whilst the BandLow signals are directed separately around the PSACEs and fed directly to all the transducer array elements (summed at each element with the output of its respective PSACE). In this manner, the lower frequencies below F_s are fed in-phase across the whole array to the elements and do not destructively interfere in the far field, whilst the higher frequencies above F_s are beamed and anti-beamed by the one or more groups of PSACEs to produce useful beaming and anti-beaming in the far-field, with the lower frequency output now remaining intact.

As will be seen, the invention provides what is effectively a sonic acoustic phased-array-antenna (PAA) comprising a number of spatially-distributed sonic acoustic transducers each connected to a phase control device - and optionally to an amplitude control device - where these control devices can be either individual to each transducer, or can be shared amongst a number of the transducers. In this PAA:

the phase control devices are implemented as variable signal-path-time-delay elements, thus allowing the PAA to operate over a broad frequency band; and

the time delays and amplitude settings applied to each transducer in the PAA are chosen so as to produce an "anti-beam" (or "anti-beams"), in which

beam direction or directions the radiation from the array (in the transmitting antenna case) or the reception sensitivity to radiation of the array (in the receiving antenna case) is reduced or indeed minimised, so creating partial or almost total "nulls" in the response pattern of the PAA.

And by suitable connection of multiple PSACEs *per* antenna element, and then by the appropriate selection of time delay and (optionally) the gain settings of each group of these PSACEs, multiple such partial or near-total nulls may be produced.

Embodiments of the invention are now described, though by way of illustration only, with reference to the accompanying diagrammatic Drawings in which:

Figure 1 shows a wideband sonic phased array according to the invention;

Figure 2 shows the arrangement used to implement multiple simultaneous beams or anti-beams in a wideband sonic phased array according to the invention;

Figure 3 shows an idealised polar response diagram of the PAA of the present invention;

Figure 4 illustrates the refinement technique used to overcome the effect of far-field cancellation of low frequencies; and

Figure 5 illustrates the use in accordance with the invention of a PAA to provide multiple nulls or anti-beams.

Figure 1 shows a wideband sonic phased array according to the invention.

The signal path connects a large number (N) of acoustic transducer means (4: only three are shown here for clarity, whereas N might typically be hundreds or even thousands of such elements) to amplitude control means (3) and then to signal-time-delay means (2) - the

sequence order of delay means 2 and amplitude control means 3 is of secondary importance only. The path then connects to the signal-splitter/combiner (5: in the transmit and receive cases respectively), and then to the signal source/detector (1:in the transmit and receive cases respectively). In the transmit-antenna case, signal flow is from left to right (as viewed), and in the receive case it is from right to left.

The arrows across delay means 2 and amplitude control means 3 signify that the delay time and amplitude control parameters respectively of these devices are controllable (i.e. are not fixed) and may, for example, be under the control of a control-computer (not shown) able to compute algorithmically the desired parameter settings for any particular desired beam(s)/ anti-beam(s) configuration.

Figure 2 shows the arrangement used to implement multiple simultaneous beams or anti-beams in a wideband sonic phased array.

Device 1 is the signal source/detector as before. Device 10 represents the structure that is shown in Fig. 1 minus the signal source/detector 1 and the N transducer means 4. The left hand port connection on a device 10 thus connects to its internal splitter/ combiner-means 5 (as detailed in Fig. 1), and the multiple right hand ports of a device 10 thus connect to its internal amplitude-control-means 3.

Device 11 is a signal-splitter/combiner-means (in the transmit and receive cases respectively) similar to the means 5. Each of devices 12 is an additional signal-splitter/combiner-means (in the transmit and receive cases respectively).

With this arrangement there is just one signal source/detector 1 and splitter/combiner 11, there are B devices 10 (where B is the total number of beams plus anti-beams to be synthesised by the PAA), and there are N devices 12, and N transducer-means 4 as before.

Figure 3 shows an idealised polar response diagram of the PAA of the present invention.

Direction line 31 shows the nominal central axis of the PAA 30 when all the phases (or time delays) are set equal to each other. Direction line 32 shows how the emission from the PAA may be "nulled" or anti-beamed in a direction not necessarily aligned with the nominal axis 31. Curve 33 shows an idealised typical polar response of such a PAA whose direction of low emission is along direction line 32, and also indicates the relatively strong emission strength in other directions. In practice multiple smaller nulling side lobes would also be present.

Figure 4 illustrates the refinement technique used to overcome the effect of far-field cancellation of the low frequencies, due to the array size being small compared to a wavelength at those lower frequencies.

Device 1 is the signal source/detector as before which is connected to a signal splitter/combiner (43) and thence to a low-pass-filter (41) and a high-pass-filter (42) in parallel channels. Low-pass-filter 41 is connected to a signal splitter/ combiner (44) which connects to all the splitter/ combiners (45) which are in turn connected to the N transducers 4 of the PAA.

High-pass-filter 42 connects to a device 10 which is the same as device 10 in Figure 2 (and which contains within it N variable-amplitude and variable-time delay elements), which in turn connects to the other combiner/ splitter ports of the combiner/splitters 45.

In this way the lower frequencies pass between the source/detector and the transducers 4 all with the same time-delay (nominally zero) and amplitude, whereas the higher frequencies are appropriately time-delayed and amplitude-controlled for each of the N transducers independently. This allows anti-beaming or nulling of the higher frequencies without global far-field nulling of the low frequencies.

Figure 5 illustrates the use of a PAA (50) of the invention to provide multiple nulls/anti-beams.

The PAA's polar response is sketched at 51 with nulls or anti-beams along direction lines 52 and 53, which are each directed towards a microphone (54, 55). These microphones are connected to the PAA 50 *via* an amplifier (not shown) to form a Public Address system.

Normally there would be a probability of howl-round (positive electro-acoustic feedback) were the system gain to be set above a certain level. Often this limiting level is sufficiently low that users of the microphone have to be very close for adequate sensitivity, which can be problematical. However, with the PAA 50 set to produce nulls or anti-beams in the directions 52,53 of the microphones 54,55, this undesirable effect can be greatly reduced, and the system gain increased to a higher level giving more useful sensitivity.

Wideband Sonic Phased Array

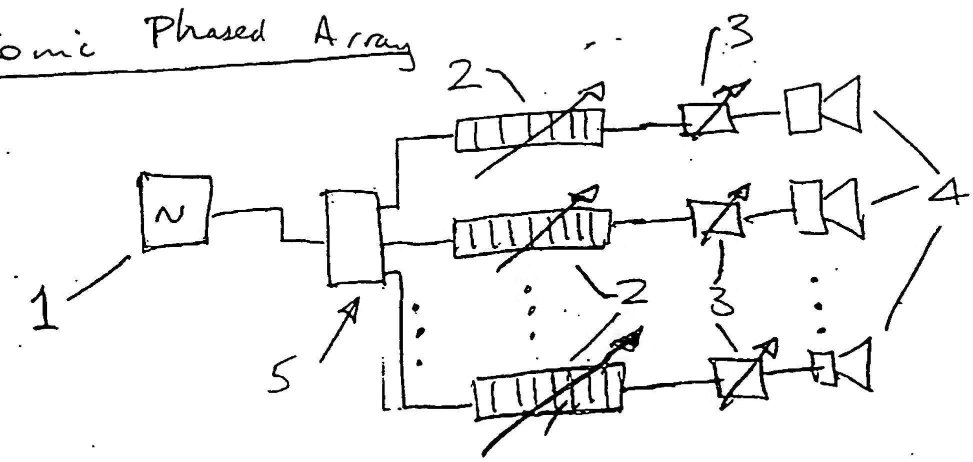


Fig. 1

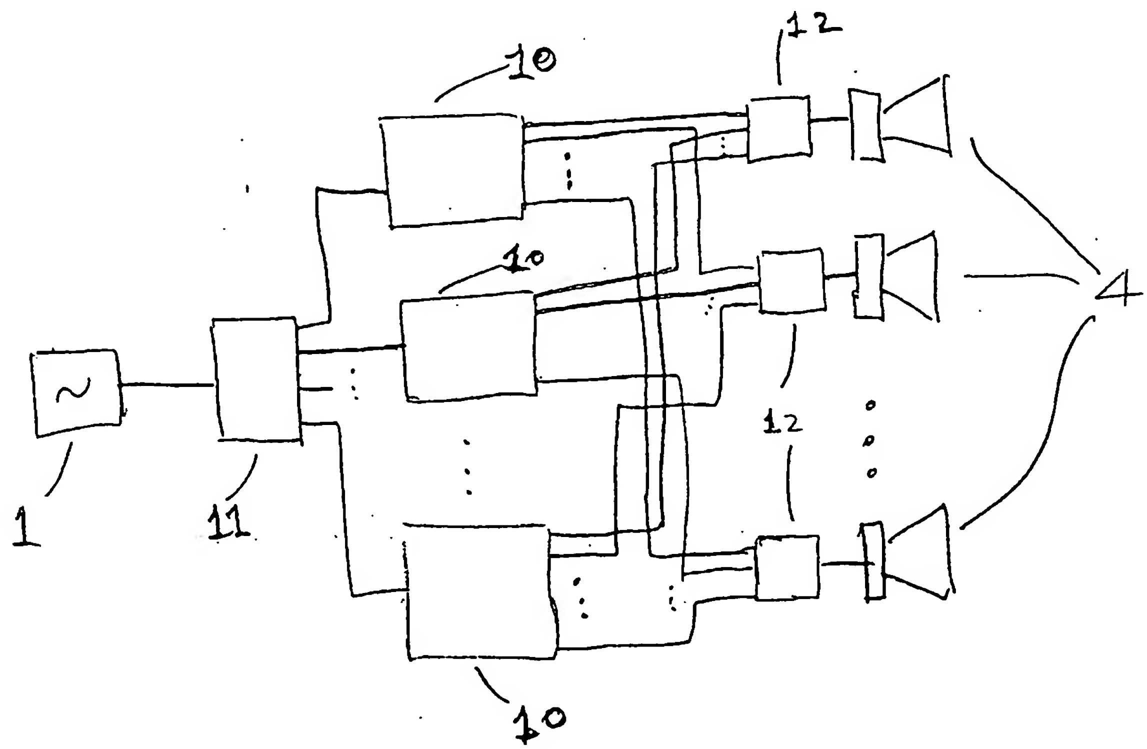


Figure 2

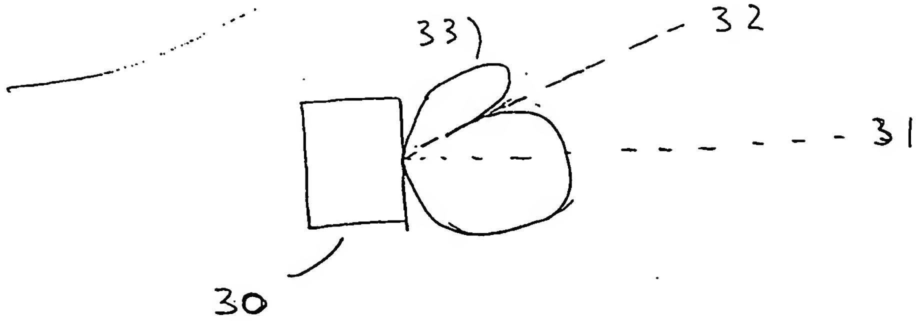


Figure 3.

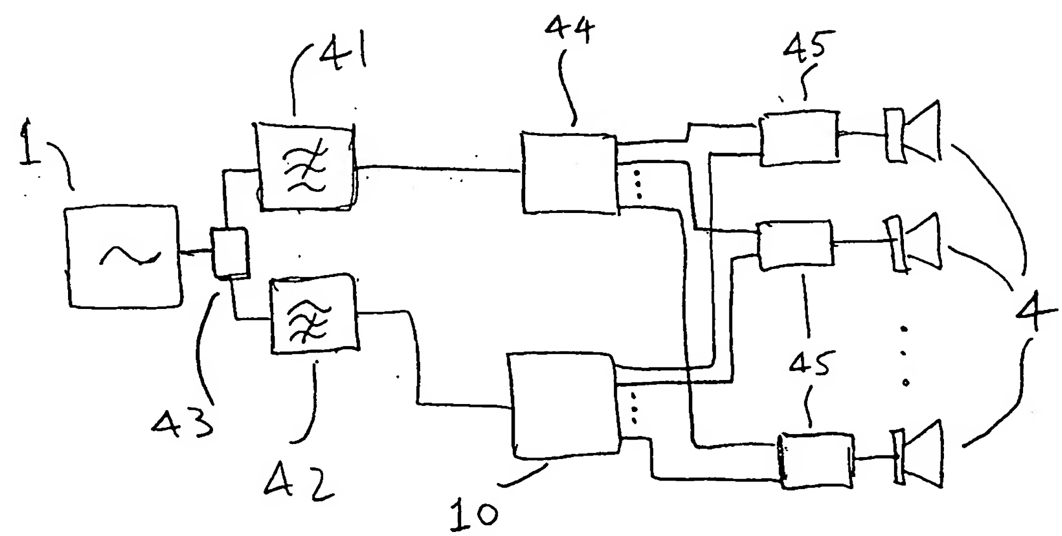
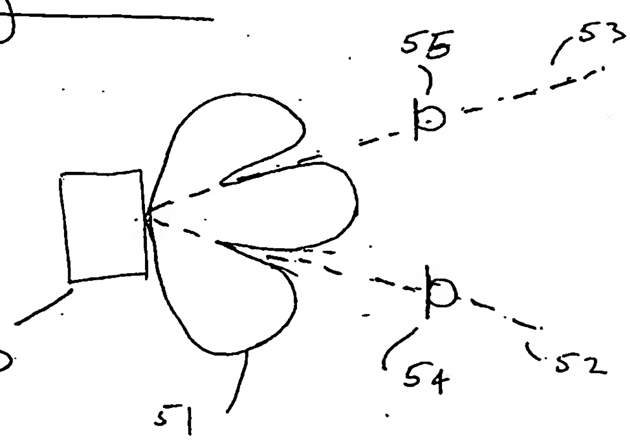


Figure 4.

Figure 5



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Clare Lyons.